EMTF FCU: User's Guide

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September 19, 2018

1 LICENSE

```
!               U.S. Geological Survey                                           !
!               1711 Illinois St                                                 !
!               Golden, CO 80401                                                 !
!                                                                                !
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!                              at the e-mail address:  akelbert@usgs.gov         !
!                                        or by phone: +1-303-273-8448            !
!                                                                                !
! EMTF FCU uses Fortran XML library (FoX),(C) 2005-2018 Toby White, Andrew Walker !
! This library is freely available under a 3-clause BSD license; which is        !
! to say that it may be used freely by any and all users; redistributed in       !
! source or binary form; provided that the copyright notices are maintained.     !
! The FoX library is not included into this distribution of EMTF FCU.            !
! It can be downloaded at http://uszla.me.uk/space/software/FoX/                 !
!                                                                                !
! Subroutines in module utils.f90 are (C) 2007 Anna Kelbert (LGPL),              !
! (C) 2002-2005 J. K. Dewhurst, S. Sharma and C. Ambrosch-Draxl (LGPL),          !
! (C) 2003 Purple Sage Computing Solutions, Inc. (GPLv2 or above).               !
! Module write_edi.f90 is an adaptation of a modified version of wrt_edi.f,      !
! originally written by Randie Mackie. In the latest version, EDI write          !
! routines have been generalized and rewritten from scratch. The author          !
! would like to thank Xavier Garcia for kindly sharing his EDI SPECTRA           !
! reading and rotation code with the author. This code has not been incorporated !
! in EMTF XML code base, but has served as an invaluable point of reference.     !
!--------------------------------------------------------------------------------!
```

2 COMPILATION

1. Install a g95 or similar Fortran 95 compiler.

2. Download the newest version of FoX library,
   http://uszla.me.uk/space/software/FoX/
   and unpack it to a directory (call it $FOX_DIR).

3. Compile FoX package

```
cd $FOX_DIR
```

```
   ./configure
   make

NB: if you move FoX in the file system, reconfigure

4. Go back to the EMTF FCU directory. Change the
   $FOX_DIR variable in the Makefile to your FoX path.
   Compile EMTF FCU by typing 'make'.
```

3 PROGRAM USAGE

The following standalone programs are available:

```
edi2xml
z2xml
xml2z
xml2edi
z2edi
```

Additionally, these standalone codes may be used for quick
coordinate rotation:

```
xml2xml
edi2edi
z2z
```

Note that, other than for the XML files, there is no guarantee
that the metadata will be preserved in the same exact format
upon a coordinate rotation, or that no information will be lost.

For the above conversion codes, Perl script counterparts
are available to perform batch processing.

edi2xml & z2xml:

depend on the FoX library and require additional
metadata files for full functionality (see below)

xml2z & xml2edi:

depend on the FoX library but do not require any
additional files; have limited functionality in
the sense that they will only work correctly
with those XML files that contain the right data
types and statistical estimates for this type
of storage

z2edi:

standalone code that requires no additional inputs

All conversion codes have an additional capability to rotate the transfer functions to an arbitrary coordinate system. This capability ought to be executed with great care for EDI files, which are inherently limited in that they do not store full covariance matrices. Rotation, therefore, invalidates the error bars in the files. While we try to do something reasonable in this case, rotation without a covariance matrix is mathematically invalid.

4 USAGE EXAMPLES

Use Case A: Convert EDI to XML, while rotating to geographic coordinates.

1. First, create a config.xml file and place it in the same directory as the original EDI file.

2. Make sure that the code is able to locate f90/DATATYPES and f90/COPYRIGHT. This is done by either copying them to your local directory, or by setting the "homedir" variable in global.f90 to your f90 folder.

3. Run

```
./edi2xml filename.edi filename.xml [verbose|silent] 0.0
```

```
Setting the third input variable to "silent" will suppress most output.

The forth input variable is any number (for an orthogonal coordinate system),
or "sitelayout" to revert back to the original site orientations.

Rotation will be lossless is the original EDI file is an EDI SPECTRA.
Otherwise, rotation will still be attempted but the output error bars
may not be physically interpreted, since the original EDI does not have
sufficient information for an unambiguous coordinate rotation.


Use Case B: Rotate EMTF XML to original site orientation.

Since the complete original site layout is now stored in the XML channels
details, rotations of XML files are fully reversible.

./xml2xml geographic.xml original.xml [verbose|silent] sitelayout


Use Case C: Convert XML to Z-file without additional rotation.

./xml2z filename.xml filename.zrr
```

5 BUG FIXES

This release includes a major bug fix. In devising the XML schema, we have attempted to maintain compatibility with the historical Society of Exploration Geophysicists (SEG) Data Interchange Standard 1987, also known as EDI, to the extent possible. This includes maintaining consistency in the element names (e.g., Z, T, etc) and the statistical estimates, where relevant. However, the definition of **variances** in the EDI files, as we surmised after reading the manual extra carefully, deviates from the definition that we've been using for computation of variances from the covariance matrices in Z-files, by a factor of 2. Specifically, variances in EDI files are given for a complex number, not for the real or imaginary part, and are therefore twice those that we computed from Z-files. This inconsistency resulted in different definitions of Z.VAR and T.VAR between the data originally converted from Z-files, and data that came from the historic EDIs.

This update eliminates this inconsistency. From now on, all XML files include the variance as defined by the historic EDI format, i.e., the variance of the complex transfer function component. To compute the standard error of a real or imaginary part, e.g., for plotting, one would divide the variance by 2, then take square root (i.e. $Std = \sqrt{Var/2}$). To plot the error bars for a real or imaginary part, one would then multiply that number by 2.

We have now adjusted (multiplied) Z.VAR and T.VAR by the factor of 2, and re-archived **all data** that are affected by this change. Your work may have been affected if a) you used the error bars in the data set (e.g., for inversion) as recorded in the XML files or the EDI files produced by the database system, and b) you used these data in combination with historic surveys converted from EDIs.

A second major bug fix involves correctly interpreting the rotations in EDI files. The old database had a warning to the effect that EDI files were not rotated. In the previous release of this database, we were trying to be careful about the error bars which can be corrupted if an EDI file is rotated in the absence of the full error covariance matrices. Unfortunately, this resulted in some occasions of file archiving where the data were not rotated to geographic, while the rotation information (ZROT) was not preserved in the archive. This is now corrected, and all data are now rotated to geographic with a caveat that the error bars are not to be trusted on these occasions.

This fix also involves the rotation of tipper data in EDI files. Specifically, in the case of an EDI file that only has ZROT information (i.e., impedance rotation) but no indication as to how the tipper are rotated (e.g., no TROT), the code defaulted to assuming that the tippers are oriented according to the channels orientations. However, it is much more typical for people who omit TROT information to mean that the tippers are oriented the same way as the impedance. So we have now changed the code's behavior to default to ZROT information for the tippers, if TROT or any other indication of tipper rotations is missing.

6 CODE IMPROVEMENTS

The updated EMTF FCU v4.0 code includes numerous improvements to correctly parse and rotate many variants of EDI files. Among the major improvements are the ability to correctly read EDI SPECTRA files and compute the full error covariances from such files. This allows for arbitrary rotations of the transfer functions without loss of information, even after conversion to the XML. We have also now implemented frequency-by-frequency rotations that allow conversion to XML of data that went through a principal axis rotation algorithm. This can now be undone for EDI files that include variable ZROT values, even though the resultant error estimates may suffer. Finally, we have implemented a general rotation algorithm that allows for rotation from an arbitrary (not necessarily orthogonal) set of channel orientations, to an arbitrary orthogonal coordinate system, or back. All of these improvements have allowed us to archive a large number of historic MT TFs that were previously unaccessible for archiving.

7 DATA ORIENTATION

MT and other EM TF data are recorded in the field in a wide variety or orientations. Most often, the channels are oriented in an "X", "L" or "T" shape such that both HX and EX point to either geomagnetic or geographic coordinates. However, in certain challenging field circumstances that occur more often than one might think, the channels are oriented to some other, arbitrary, directions that possibly deviate from orthogonal.

For correct interpretation of the data, it is critical that these channel orientations are correctly recorded. However, in an analysis that wishes to use the measurements jointly with other data, it is also critical that the user rotates the transfer functions to a common orthogonal coordinate system. Usually scientists want the data to point to geographic North.

Many old data files are ambiguous with respect to data orientation, and often miss critical pieces of information, or contain several conflicting messages. Moreover, EDI data files (unless they include SPECTRA) do not contain sufficient information for statistically correct rotation of error bars. Our original intention was, therefore, to archive the data as they are, without a data rotation. We did not include a data rotation in the XML files, and presumed that the data are oriented to site layout, as defined by the input and output channel orientations, example:

```
<InputChannels ref="site" units="m">
<Magnetic name="Hx" orientation="0.0" x="0.0" y="0.0" z="0.0"/>
<Magnetic name="Hy" orientation="90.0" x="0.0" y="0.0" z="0.0"/>
</InputChannels>
<OutputChannels ref="site" units="m">
<Magnetic name="Hz" orientation="0.0" x="0.0" y="0.0" z="0.0"/>
<Electric name="Ex" orientation="0.0" x="-50.0" y="0.0" z="0.0" x2="50.0" y2="0.0" z2="0.0"/>
<Electric name="Ey" orientation="90.0" x="0.0" y="-40.0" z="0.0" x2="0.0" y2="40.0" z2="0.0"/>
</OutputChannels>
```

We have since come to realize that this strategy can result in severe data misinterpretation by scientists who are not well versed with certain subtleties of MT data. Moreover, since the channel orientations in the file had to match the orientation of the TFs, it didn't allow us to preserve the original site layout, making any rotation irreversible. Finally, a scientist couldn't quickly discern whether or not the data were oriented to orthogonal geographic or to some other layout, without checking the orientations of all channels. Even though we try to specify the declination, if known, there wasn't enough information in the files to know whether or not the data were collected in geomagnetic coordinates in the first place.

We have decided to adjust the XML schema to include **unambiguous rotation information**. Our new strategy is to always rotate the transfer functions to orthogonal geographic for archival at the database. This is a convention that we have adopted for user convenience. We should note that the updated XML format has enough information to unambiguously store data in any orientation, and also allows for reversible rotations. For this, we had to redefine the meaning of the channel orientations completely.

First of all, we added a new element to the XML `<Site>` header, right after `<Location>` (it's that important!). Two options are allowed:

```
<Orientation angle_to_geographic_north="0.0">orthogonal</Orientation>
```

or,

```
<Orientation>sitelayout</Orientation>
```

In the database, the files will be oriented to orthogonal geographic, as indicated by the first variant of the new `<Orientation>` element. Both `orthogonal` and `sitelayout` are keywords, and no other keywords are supported. More generally, the angle to geographic North can of course be arbitrary. Alternatively, if the orientation is defined by the site layout, it no longer necessarily has to be (or presumed to be) orthogonal. Even as the data are archived in orthogonal geographic, we will always strive to archive the channel information in their original site layout. If the data are oriented to site layout, then and only then the channel orientations will also define the data orientations. Codes have been developed to revert any rotation back to the site layout, if needed, as well as to rotate to any other arbitrary orthogonal coordinate system. These codes will be made freely available.

To better match the new meaning of the channels, we have now encompassed them with a new element, `<SiteLayout>`. The channels are no longer rotated with the data, as they merely indicate the original site layout, whenever this information is known. No other changes to the channel information have been made in this update. Example:

```
<SiteLayout>
<InputChannels ref="site" units="m">
<Magnetic name="Hx" orientation="0.0" x="0.0" y="0.0" z="0.0"/>
<Magnetic name="Hy" orientation="90.0" x="0.0" y="0.0" z="0.0"/>
</InputChannels>
<OutputChannels ref="site" units="m">
<Magnetic name="Hz" orientation="0.0" x="0.0" y="0.0" z="0.0"/>
<Electric name="Ex" orientation="0.0" x="-50.0" y="0.0" z="0.0" x2="50.0" y2="0.0" z2="0.0"/>
<Electric name="Ey" orientation="90.0" x="0.0" y="-40.0" z="0.0" x2="0.0" y2="40.0" z2="0.0"/>
</OutputChannels>
</SiteLayout>
```

Additional information (such as "geomagnetic") may be specified as a `SiteLayout` attribute, but we opted against providing this information. It can be discerned from the channels orientations, which provide a significantly more general way to record this information. Duplication of information in both verbal and numeric form leads to conflicts and confusion more than to clarity.

Finally, we have also added an optional descriptive element called `<RotationInfo>`. It has helped us to record any subtleties and ambiguities with respect to discerning the data rotation that we had to overcome before the data could be archived. Our human interpretation of human omissions from 20-30 yrs ago is not flawless. We consider these considerations an important piece of information for anybody who has concerns about any particular data site and needs to find the root of the problem.

8 DATA CITATIONS

Added **Digital Object Identifiers (DOIs)** for Electromagnetic Transfer Functions. DOIs, attributed directly to data sets, allow us to give proper credit to the very significant effort of data collection, allowing to cite the data sets directly in any new publications in lieu (or in addition to) data interpretation papers. This provides a great incentive of data sharing that was never before in place in magnetotelluric community. DOI attribution has additional benefits, which include the ability to track the usage of any particular data set and notify the users of any updates as necessary.

To make this possible, we reached out to the authors of every data set that we archived or were planning to archive to obtain the critical information for the data citation, namely the authors, years of data collection, title, acknowledgements, and selected publications. We found that this is a learning process for everyone involved. The concept of data citation was so new to this community that most did not understand our questions at first, thinking that its a publication reference that we were after. When we explained that this was truly a way to give credit for data collection (NOT for data interpretation as has been customary until now), many of our colleagues came to value and appreciate this opportunity. The authorship of the data sets often turns to be notably different from that in the final publications, if such publications exist.

The greatest technical challenge was achieving the right granularity of the DOIs. A unique DOI is given and automatically included within any XML data file upon submission to EMTF database. However, for data citations to be practical in publications, one would need a data DOI that points to a collection of data, such as a survey, united by the common authors, dates, geographical area, and purpose. Jointly with IRIS, we have devised a strategy to attribute a unique DOI to a geophysical survey. This goes under a "Survey DOI" and is available along with the complete data citation, whenever any site is selected and opened in the database. Users are strongly encouraged to cite Survey DOIs in their publications, just like they would cite a paper. All data in the database were re-archived with the authorship attribution information.

For example, to cite the USArray magnetotelluric transfer functions, one would use the following reference:

Schultz, A., G. D. Egbert, A. Kelbert, T. Peery, V. Clote, B. Fry, S. Erofeeva and staff of the National Geoelectromagnetic Facility and their contractors (2006-2018). "USArray TA Magnetotelluric Transfer Functions". doi:10.17611/DP/EMTF/USARRAY/TA. Retrieved from the IRIS database on Feb 26, 2016

The date of retrieval from the database would reflect the date when the data were accessed. This citation should appear in the References section of the manuscript. In the text of a paper, this citation looks like "Schultz *et al* (2006-2018)". Some journals complain when they see this at first, but they all are eventually ok with this format.

Data acknowledgements are, ideally, included verbatim in the relevant section of the paper. For example, here's the full acknowledgement for USArray:

USArray MT TA project was led by PI Adam Schultz and Gary Egbert. They would like to thank the Oregon State University MT team and their contractors, lab and field personnel over the years for assistance with data collection, quality control, processing and archiving. They also thank numerous districts of the U.S. Forest Service, Bureau of Land Management, the U.S. National Parks, the collected State land offices, and the many private landowners who permitted access to acquire the MT TA data. USArray TA was funded through NSF grants EAR-0323311,

IRIS Subaward 478 and 489 under NSF Cooperative Agreement EAR-0350030 and EAR-0323309, IRIS Subaward 75-MT under NSF Cooperative Agreement EAR-0733069 under CFDA No. 47.050, and IRIS Subaward 05-OSU-SAGE under NSF Cooperative Agreement EAR-1261681.

If you heavily use USArray MT data in your publication, you are encouraged to include the complete text of this acknowledgement in your own acknowledgement for the paper. If the word limit doesn't allow that, please truncate it as necessary but still include it. Please note that a mere acknowledgement of the data, without a data citation as provided above, is not appropriate. This data citation is the only credit these people get for their many years of hard work in data collection and processing. Thank you to those of you who already follow these citation practices, that's much appreciated.

To cite the EMTF database, please use:

Kelbert, A., G.D. Egbert and A. Schultz (2011), IRIS DMC Data Services Products: EMTF, The Magnetotelluric Transfer Functions, https://doi.org/10.17611/DP/EMTF.1.

This information is also accessible by clicking the "Citations" link at the top of EMTF database website.

9 CREATING SPUD XML FILES

This comment only applies if you would like to use the software to create XML files for archiving or self-describing data storage, using z2xml or edi2xml.

In this case, you need to create an XML configuration file called config.xml and place it in the same directory as your input data. Example files are pasted below.

This is where any user-defined information about the experiment is stored. You could also use the configuration file to specify one or all XML lists with additional metadata: Sites.xml, Runs.xml, Channels.xml. The lists, if specified, should contain experiment metadata information about runs and the sites, as described in module `read_lists.f90`. Examples below.

NB: For the XML lists, the attributes are optional; they are automatically inserted for easier reading with Matlab. All elements are also optional.

The program looks for the configuration file and the optional XML lists in the same directory where the input file is located. If the lists are not found, the programs run without the additional information.

NB: If you have the lists, use them by first running z2xml, then xml2edi. Note that the program z2edi does not require FoX library to be installed, and it does not use the additional XML information.

10 EXAMPLE CONFIG.XML TO ARCHIVE Z-FILES

```
<Configuration>
<!-- optional; used to indicate that time series are also archived at IRIS DMC;
         the network should match -->
    <TimeSeriesArchived>1</TimeSeriesArchived>
    <Network>EM</Network>
<!-- Project / Survey combination used to allocate survey DOI;
         Project should contain no spaces -->
<Project>YSRP</Project>
<Survey>Yellowstone-Snake River Plain</Survey>
<!-- Project.SiteID.YearCollected used to create a unique data ID in SPUD -->
<YearCollected>2004</YearCollected>
<Country>USA</Country>
<!-- required, comma-separated list of data types. See list of possible types -->
<Tags>impedance,tipper</Tags>
<!-- required, except for DOI which should be omitted if it does not yet exist -->
        <Citation>
       <Title>Deep Magnetotelluric Sounding along the Yellowstone-
                    Snake River hotspot track</Title>
       <Authors>Catherine deGroot-Hedlin, Steven Constable, Karen Weitemeyer</Authors>
       <Year>2003-2004</Year>
       <DOI></DOI>
        </Citation>
<!-- supported options: Unrestricted Release / Academic Use Only / Conditions Apply -->
<ReleaseStatus>Unrestricted Release</ReleaseStatus>
<!-- all provenance and processing information is optional but useful -->
<AcquiredBy>UCSD/Catherine deGroot-Hedlin</AcquiredBy>
<Creator>
<Name>Gary Egbert and Anna Kelbert</Name>
<Email>egbert@coas.oregonstate.edu</Email>
<Org>Oregon State University</Org>
<OrgUrl>http://oregonstate.edu</OrgUrl>
</Creator>
<Submitter>
<Name>Anna Kelbert</Name>
```

```
<Email>anya@coas.oregonstate.edu</Email>
<Org>Oregon State University</Org>
<OrgUrl>http://oregonstate.edu</OrgUrl>
</Submitter>
<ProcessedBy>Gary Egbert and Anna Kelbert</ProcessedBy>
<ProcessingSoftware>
<Name>EMTF</Name>
<LastMod>2008-06-28</LastMod>
<Author>Gary Egbert</Author>
</ProcessingSoftware>
<!-- if these extensions are present, the corresponding files
         are also submitted and displayed -->
<Image>png</Image>
<Original>zrr</Original>
<!-- optional lists that allow to provide much additional metadata -->
<RunList>Runs.xml</RunList>
<SiteList>Sites.xml</SiteList>
<ChannelList>Channels.xml</ChannelList>
<!-- this option is for those who only wish to upload the metadata -->
<MetadataOnly>0</MetadataOnly>
</Configuration>
```

11 EXAMPLE CONFIG.XML TO ARCHIVE EDI FILES

```
<Configuration>
<!-- set this to zero or omit if the time series are not archived at IRIS DMC -->
<TimeSeriesArchived>0</TimeSeriesArchived>
<Network>EM</Network>
<!-- optionally, specify an external URL for the data or metadata -->
<ExternalUrl></ExternalUrl>
<ExternalUrlInfo></ExternalUrlInfo>
<!-- Project / Survey combination used to allocate survey DOI; Project should contain no spaces -
<Project>EMSOC</Project>
<Survey>Sant Andreas Fault</Survey>
<!-- Project.SiteID.YearCollected used to create a unique data ID in SPUD -->
<YearCollected>2005-2006</YearCollected>
<Country>USA</Country>
<!-- required, comma-separated list of data types. See list of possible types -->
<Tags>
```

```
impedance,tipper
</Tags>
<!-- data citation -->
<Citation>
<Title>Magnetotelluric transfer functions in the San Andreas Fault zone, CA, USA</Title>
<Authors>Becken, M., Ritter, O., Park, S. K., Bedrosian, P. A., Weckmann, U. and Weber, M.</Author
<Year>1999-2010</Year>
<SurveyDOI>doi:10.17611/DP/EMTF/EMSOC/SAF</SurveyDOI>
</Citation>
<THANKS>THANKS.txt</THANKS>
<PAPERS>PAPERS.txt</PAPERS>
<!-- optional additional copyright information -->
<README>readme.txt</README>
<!-- supported options: Unrestricted Release / Academic Use Only / Conditions Apply -->
<ReleaseStatus>Paper Citation Required</ReleaseStatus>
<!-- allows to supplement missing provenance and processing information from files -->
<AcquiredBy>Stephen K. Park</AcquiredBy>
<Creator>
<Name>Stephen K. Park</Name>
<Email>magneto@ucrmt.ucr.edu</Email>
<Org>University of California Riverside</Org>
<OrgUrl>http://www.ucr.edu/</OrgUrl>
</Creator>
<Submitter>
<Name>Lana Erofeeva</Name>
<Email>serofeev@coas.oregonstate.edu</Email>
<Org>Oregon State University</Org>
<OrgUrl>http://oregonstate.edu</OrgUrl>
</Submitter>
<ProcessedBy>Stephen K. Park</ProcessedBy>
<ProcessingSoftware>
<Name>Jimmy Larsen's robust processing code (using negative conjugate of output)</Name>
<LastMod>01/21/06</LastMod>
<Author></Author>
</ProcessingSoftware>
<SignConvention>exp(+ i\omega t)</SignConvention>
<!-- tells the conversion codes how to parse the EDI and whether to write the INFO block to XML -
<ComputeSiteCoords>0</ComputeSiteCoords>
<DateFormat>MM/DD/YY</DateFormat>
<DummyDataValue>.10000000E+33</DummyDataValue>
```

```
<ChannelsOnTwoLines>1</ChannelsOnTwoLines>
<UseImpedanceRotationForAll>1</UseImpedanceRotationForAll>
<ParseEDIInfo>0</ParseEDIInfo>
<WriteEDIInfo>0</WriteEDIInfo>
<IgnoreSiteNameInFile>1</IgnoreSiteNameInFile>
<DefaultSiteName>Parkfield, CA, USA</DefaultSiteName>
<DefaultStartTime>2006-06-01T00:00:00</DefaultStartTime>
<DefaultEndTime>2006-06-01T00:00:00</DefaultEndTime>
<DefaultDataQuality>5</DefaultDataQuality>
<DataQualityComment>Default data quality assigned to the survey at archiving</DataQualityComment>
<!-- this option is for those who only wish to upload the metadata -->
<MetadataOnly>0</MetadataOnly>
<!-- if these extensions are present, the corresponding files are also submitted to SPUD, and disp
<Image>png</Image>
<Original>edi</Original>
<!-- optional attachment - full name required -->
<Attachment></Attachment>
<AttachmentInfo></AttachmentInfo>
</Configuration>
```

12 EXAMPLE LIST FILES FORMAT

Sites.xml, Runs.xml and Channels.xml are the lists with sample elements described below. These lists provide optional metadata input for archiving of MT transfer functions with SPUD.

The same lists are also used by the MT team at OSU for archiving of the time series with IRIS. Therefore, they contain additional information for internal OSU (and IRIS) use that an outside user may not know or care about. It is completely fine to leave any of the elements out of your list. Archiving with EMTF FCU will use whatever is available, and ignore the missing information (at least that is the intention!)

Note: if these lists are written with, e.g., Matlab tools, additional attributes may be written to these files (example: `idx=`1” type=”double” size=”1 1””). These attributes, if present, are used for faster reading with Matlab. They are not required for EMTF FCU, and they won’t create a problem, either. The use of such attributes that detail the content of the XML elements is completely optional.

```
  <Site>
    <ID>CAM01</ID>
    <Description>Earl Lake, CA, USA</Description>
    <Location>
```

```
    <Latitude>41.87624</Latitude>
    <Longitude>-124.1900079166 7</Longitude>
    <Elevation>0.975</Elevation>
  </Location>
  <Declination>16.6</Declination>
  <TimePeriod>
    <Start>2007-08-31T21:51:38</Start>
    <End>2007-09-20T18:42:08</End>
  </TimePeriod>
  <QualityRating>5</QualityRating>
  <GoodFromPeriod>10</GoodFromPeriod>
  <GoodToPeriod>20000</GoodToPeriod>
  <QualityComments>great TF from 10 to 10000 secs (or longer)</QualityComments>
  <BestTF>CAM01bc_K1x.zrr</BestTF>
  <RunList>CAM01a CAM01b CAM01c</RunList>
  <NoGPS>0</NoGPS>
  <Comments>Data Problem Report available at
            http://www.iris.edu/data/dpr.htm</Comments>
</Site>

<Run>
  <ID>CAM01a</ID>
  <siteID>CAM01</siteID>
  <Manufacturer>Barry Narod</Manufacturer>
  <Instrument>NIMS 2612-04</Instrument>
  <Location>
    <Latitude>41.87636</Latitude>
    <Longitude>-124.19003166667</Longitude>
    <Elevation>2.8</Elevation>
  </Location>
  <Declination>16.6</Declination>
  <TimePeriod>
    <Start>2007-08-31T21:51:38</Start>
    <End>2007-08-31T22:52:15</End>
  </TimePeriod>
  <Ex_wire_length>100</Ex_wire_length>
  <Ey_wire_length>100</Ey_wire_length>
  <SamplingInterval>1</SamplingInterval>
  <ClockOffset>0</ClockOffset>
  <NewEpoch>1</NewEpoch>
  <Count>1</Count>
```

```
  <NChannels>5</NChannels>
  <SiteInstalledBy/>
  <FieldComments/>
  <MetaDataCheckedBy/>
  <Comments/>
  <Errors/>
</Run>

<Channel>
  <ID>LFN</ID>
  <Name>Hx</Name>
  <siteID>CAM01</siteID>
  <runID>CAM01a</runID>
  <Instrument>Magnetometer</Instrument>
  <InstrumentType>fluxgate</InstrumentType>
  <Manufacturer>Barry Narod</Manufacturer>
  <InstrumentName>NIMS</InstrumentName>
  <InstrumentID>2612-04</InstrumentID>
  <InstrumentConfig/>
  <TimePeriod>
    <Start>2007-08-31T21:51:38</Start>
    <End>2007-08-31T22:52:15</End>
  </TimePeriod>
  <SamplingRate>
    <Value>1</Value>
    <Units>Hz</Units>
  </SamplingRate>
  <DipoleLength>0</DipoleLength>
  <Orientation>16.6</Orientation>
  <LowPassCutoff>0.5</LowPassCutoff>
  <HighPassCutoff>0</HighPassCutoff>
  <TimeOffset>-0.192</TimeOffset>
  <Correction>
    <Value>0</Value>
    <Type>base shift</Type>
  </Correction>
  <Conversion>0.01</Conversion>
  <Comments>x 0.01 to get nT, Hx base shift 0 nT</Comments>
</Channel>
```

12.1 DATA TYPES

In addition to supporting most standard data types adopted from the EDI format, we have made an effort to devise a scheme that would potentially be easily extensible to more general data types and statistical error estimates.

In order to convert a survey from EDI to SPUD XML, a user would visually inspect the EDI files to see which data types were present. The user would then define a list of comma-separated "Tags" in an XML configuration file, e.g., "impedance, tipper" (see tables 1 and 2 for lists of allowed tags). As we can see from the tables, five primary and 15 derived data types are currently allowed. However, a new data type (and the corresponding tag) may be added at any time by setting up a new data type XML definition, **without any code modification**.

As can be seen from XML definition examples and tables below, each data type tag has a corresponding EDI name which is used for the one-to-one conversion between the formats, as well as to store the actual data matrices in the XML. The format conversion code then goes through the tag list to add the definitions of each of the data types to SPUD XML, point to the corresponding online documentation, and set up the matrices for storage and XML writing.

This database restricts itself to EM transfer functions, in the most general sense. To this end, every data type is explicitly organized by input and output channels. The common name of the data type (e.g., Zxy, for an impedance component) is also provided for user convenience, but isn't employed in any of the conversion tools.

In the XML file, the data are grouped by period. For each period, the data components are grouped by data type. The syntax for the element names echoes that of the EDI files: it's an uppercase abbreviation, as described in Tables 1 and 2. Within each data type, there may be multiple components, however, each data type has a specific number of input and output field components, and all components within a type have the same units. For example, derived data types `apparent_resistivity` (RHO) and `impedance_phase` (PHS) are stored as two different data types, which all components of `phase_tensor` (PT) are stored together. Any statistical error estimates are stored in a similar manner, with the element name formed of the data type abbreviation and the abbreviation of the statistical error estimate (e.g., Z.VAR, Z.INVSIGCOV, Z.RESIDCOV, etc).

Defining a new primary or derived data type is as simple as creating a new simple XML file in the DATATYPES subdirectory of EMTF FCU code, e.g.,

```
<DataType name="Z" type="complex" output="E" input="H" units="[mV/km]/[nT]">
<Description>MT impedance</Description>
```

EDI/ XML Name	Real/ Complex	Output	Input	Units	Description	Tag
Z	complex	E	H	[mV/km]/[nT]	MT Impedance	impedance
Z	complex	E	H	[mV/km]/[nT]	MT Impedance - off diagonal components only	off_diagonal_impedance
T	complex	H	H	[]	Vertical Field Transfer Functions (Tipper)	tipper
Q	complex	E	H	[mV/km]/[nT]	MT Interstation Impedance	interstation_impedance
P	complex	H	H	[]	Interstation Magnetic Field Transfer Functions	interstation_transfer_functions

Table 1: List of primary data types currently supported by the XML format and the conversion tools. Additional primary data types may be easily added without any modification to the conversion codes: a simple XML file that described the new data type must be added to the DATATYPES directory of the format conversion tools.

EDI/ XML Name	Real/ Complex	Output	Input	Units	Description	Tag	Derived From
PT	real	E	H	[]	Phase Tensor	phase_tensor	impedance
RHO	real	E	H	Ohm	Apparent Resistivities	apparent_resistivity	impedance
PHS	real	E	H	degrees	Impedance Phase	impedance_phase	impedance
ZEFF	complex	E	H	[mV/km]/[nT]	Effective Impedance	effective_impedance	impedance
ZDET	complex	E	H	[mV/km]/[nT]	Impedance Determinant	impedance_determinant	impedance
ZSTRIKE	real	E	H	[]	Impedance strike	impedance_strike	impedance
ZSKEW	real	E	H	[]	Impedance skew	impedance_skew	impedance
ZELLIP	real	E	H	[]	Impedance ellipticity	impedance_ellipticity	impedance
TIPMAG	real	H	H	[]	Tipper magnitude	tipper_magnitude	tipper
TIPPHS	real	H	H	degrees	Tipper phase	tipper_phase	tipper
INDMAG	real	H	H	[]	Induction Arrows: magnitude	induction_arrow_magnitude	tipper
INDANG	real	H	H	degrees	Induction Arrows: angle (Parkinson convention)	induction_arrow_angle	tipper
TSTRIKE	real	H	H	[]	Tipper strike	tipper_strike	tipper
TSKEW	real	H	H	[]	Tipper skew	tipper_skew	tipper
TELLIP	real	H	H	[]	Tipper ellipticity	tipper_ellipticity	tipper

Table 2: List of derived data types currently supported by the XML format and the conversion tools. Additional derived data types may be easily added without any modification to the conversion codes: a simple XML file that described the new data type must be added to the DATATYPES directory of the format conversion tools. This preliminary list is compiled based on *Wight* (1988), *Hobbs* (1992) and *Becken et al.* (2008).

```
<Intention>primary data type</Intention>
<Tag>impedance</Tag>
</DataType>

<DataType name="RHO" type="real" input="H" output="E" units="[Ohm m]">
<Description>Apparent resistivity computed from MT impedance</Description>
<Intention>derived data type</Intention>
<Tag>apparent_resistivity</Tag>
<DerivedFrom>impedance</DerivedFrom>
<SeeAlso>impedance_phase</SeeAlso>
</DataType>
```

12.2 STATISTICAL ESTIMATES

The list of supported statistical error estimates is based on *Wight* (1988) and *Eisel and Egbert* (2001):

```
variance
covariance
inverse_signal_covariance
residual_covariance
coherence
multiple_coherence
signal_amplitude
signal_noise
```

These are defined, similarly, in the DATATYPES directory, e.g.,

```
<Estimate name="INVSIGCOV" type="complex">
<Description>Inverse Coherent Signal Power Matrix (S)</Description>
<Intention>signal power estimate</Intention>
<Tag>inverse_signal_covariance</Tag>
</Estimate>
```

However, each statistical error estimate requires a specific matrix storage to be defined within the code. Hence, additional error estimates may be introduced with code modification.

12.3 SAMPLE FINAL EMTF XML FORMATTED FILE


```
<?xml version="1.0" encoding="UTF-8"?>
<EM_TF>
  <Description>Magnetotelluric Transfer Functions</Description>
  <ProductId>USArray.ORL09.2006</ProductId>
  <SubType>MT_TF</SubType>
  <Notes/>
  <Tags>impedance,tipper</Tags>
  <ExternalUrl>
    <Description>IRIS DMC MetaData</Description>
    <Url>http://www.iris.edu/mda/EM/ORL09</Url>
  </ExternalUrl>
  <PrimaryData>
    <Filename>ORL09bc_J9.png</Filename>
  </PrimaryData>
  <Attachment>
    <Filename>ORL09bc_J9.zrr</Filename>
    <Description>The original used to produce the XML</Description>
  </Attachment>
  <Provenance>
    <CreateTime>2013-07-19T15:50:21</CreateTime>
    <CreatingApplication>EMTF File Conversion Utilities 3.0</CreatingApplication>
    <Creator>
      <Name>Gary Egbert and Lana Erofeev</Name>
      <Email>egbert@coas.oregonstate.edu</Email>
      <Org>Oregon State University</Org>
      <OrgUrl>http://oregonstate.edu</OrgUrl>
    </Creator>
    <Submitter>
      <Name>Anna Kelbert</Name>
      <Email>anya@coas.oregonstate.edu</Email>
      <Org>Oregon State University</Org>
      <OrgUrl>http://oregonstate.edu</OrgUrl>
    </Submitter>
  </Provenance>
  <Copyright>
    <Citation>
      <Title>USArray TA Magnetotelluric Transfer Functions</Title>
      <Authors>Adam Schultz, Gary D. Egbert, Anna Kelbert</Authors>
```

```
      <Year>2006</Year>
    </Citation>
    <ReleaseStatus>Unrestricted Release</ReleaseStatus>
    <ConditionsOfUse>
    All data and metadata for this survey are available free of charge
and may be copied freely, duplicated and further distributed provided
this data set is cited as the reference.
 While the author(s) strive to provide data and metadata of best possible
quality, neither the author(s) of this data set, not IRIS make any claims,
promises, or guarantees about the accuracy, completeness, or adequacy
of this information, and expressly disclaim liability for errors and
omissions in the contents of this file.
 Guidelines about the quality or limitations of the data and metadata, as
obtained from the author(s), are included for informational purposes only.
    </ConditionsOfUse>
  </Copyright>
  <Site>
    <Project>USArray</Project>
    <Survey>TA</Survey>
    <YearCollected>2006</YearCollected>
    <Id>ORL09</Id>
    <Name>Hoppin Springs, OR , USA</Name>
    <Location datum="WGS84">
      <Latitude>42.085064</Latitude>
      <Longitude>-117.552100</Longitude>
      <Elevation units="meters">1978.750</Elevation>
      <Declination epoch="1995.0">15.300</Declination>
    </Location>
<Orientation angle_to_geographic_north="0.000">orthogonal</Orientation>
    <AcquiredBy>GSY-USA, Inc.</AcquiredBy>
    <Start>2006-10-13T22:50:32</Start>
    <End>2006-10-31T17:47:39</End>
    <RunList>ORL09a ORL09b ORL09c</RunList>
    <DataQualityNotes>
      <Rating>5</Rating>
      <GoodFromPeriod>8.000</GoodFromPeriod>
      <GoodToPeriod>20000.000</GoodToPeriod>
      <Comments author="Gary Egbert and Lana Erofeev">
        great TF from 10 to 10000 secs (or longer)
      </Comments>
```

```
  </DataQualityNotes>
  <DataQualityWarnings>
    <Flag>0</Flag>
    <Comments author="Gary Egbert and Lana Erofeev"></Comments>
  </DataQualityWarnings>
</Site>
<FieldNotes run="ORL09b">
  <Instrument>
    <Manufacturer>Barry Narod</Manufacturer>
    <Name>NIMS</Name>
    <Id>2406-13</Id>
    <Settings/>
  </Instrument>
  <Magnetometer type="fluxgate">
    <Manufacturer>Barry Narod</Manufacturer>
    <Name>NIMS</Name>
    <Id>2406-13</Id>
    <Settings/>
  </Magnetometer>
  <Dipole name="Ex" type="wire">
    <Manufacturer>Steve Park</Manufacturer>
    <Length units="meters">100.000</Length>
    <Azimuth units="degrees">15.300</Azimuth>
    <Electrode location="N" number="Calib">
      Pb-PbCl2 single chamber liquid filled porous cell
    </Electrode>
    <Electrode location="S" number="Calib">
      Pb-PbCl2 single chamber liquid filled porous cell
    </Electrode>
  </Dipole>
  <Dipole name="Ey" type="wire">
    <Manufacturer>Steve Park</Manufacturer>
    <Length units="meters">100.000</Length>
    <Azimuth units="degrees">105.300</Azimuth>
    <Electrode location="E" number="Calib">
      Pb-PbCl2 single chamber liquid filled porous cell
    </Electrode>
    <Electrode location="W" number="Calib">
      Pb-PbCl2 single chamber liquid filled porous cell
    </Electrode>
```

```
  </Dipole>
  <Errors>Found data gaps (1). Gaps of unknown length: 1 [843382].] ]</Errors>
  <SamplingRate units="Hz">1.000</SamplingRate>
  <Start>2006-10-14T00:08:14</Start>
  <End>2006-10-23T18:24:54</End>
</FieldNotes>
<FieldNotes run="ORL09c">
  <Instrument>
    <Manufacturer>Barry Narod</Manufacturer>
    <Name>NIMS</Name>
    <Id>2406-13</Id>
    <Settings/>
  </Instrument>
  <Magnetometer type="fluxgate">
    <Manufacturer>Barry Narod</Manufacturer>
    <Name>NIMS</Name>
    <Id>2406-13</Id>
    <Settings/>
  </Magnetometer>
  <Dipole name="Ex" type="wire">
    <Manufacturer>Steve Park</Manufacturer>
    <Length units="meters">100.000</Length>
    <Azimuth units="degrees">15.300</Azimuth>
    <Electrode location="N" number="Calib">
      Pb-PbCl2 single chamber liquid filled porous cell
    </Electrode>
    <Electrode location="S" number="Calib">
      Pb-PbCl2 single chamber liquid filled porous cell
    </Electrode>
  </Dipole>
  <Dipole name="Ey" type="wire">
    <Manufacturer>Steve Park</Manufacturer>
    <Length units="meters">100.000</Length>
    <Azimuth units="degrees">105.300</Azimuth>
    <Electrode location="E" number="Calib">
      Pb-PbCl2 single chamber liquid filled porous cell
    </Electrode>
    <Electrode location="W" number="Calib">
      Pb-PbCl2 single chamber liquid filled porous cell
    </Electrode>
```

```
  </Dipole>
  <Errors>No GPS. No GPS messages. Start time unknown.Found data gaps (1).
  Unable to compute start time because of a gap in sequence numbers before
  the first valid GPS message.Please delete all data up to and including
  index 684284. Gaps of unknown length: 1 [684284].] ]</Errors>
  <SamplingRate units="Hz">1.000</SamplingRate>
  <Start>2006-10-23T19:42:54</Start>
  <End>2006-10-31T17:47:39</End>
</FieldNotes>
<ProcessingInfo>
  <SignConvention>exp(+ i\omega t)</SignConvention>
  <RemoteRef type="Robust Remote Reference"/>
  <RemoteInfo>
    <Site>
      <Project>USArray</Project>
      <Survey>TA</Survey>
      <YearCollected>2006</YearCollected>
      <Id>ORJ09</Id>
      <Name>Little Mud Flat, OR , USA</Name>
      <Location datum="WGS84">
        <Latitude>43.362526</Latitude>
        <Longitude>-117.745400</Longitude>
        <Elevation units="meters">1304.300</Elevation>
      </Location>
    </Site>
    <FieldNotes run="ORJ09b">
      <Instrument>
        <Manufacturer>Barry Narod</Manufacturer>
        <Name>NIMS</Name>
        <Id>2501-19</Id>
        <Settings/>
      </Instrument>
      <Dipole name="Ex">
        <Length units="meters">100.000</Length>
      </Dipole>
      <Dipole name="Ey">
        <Length units="meters">100.000</Length>
      </Dipole>
      <Errors>Found data gaps (1). Gaps of unknown length: 1 [770354].</Errors>
      <SamplingRate units="Hz">1.000</SamplingRate>
```

```
      &lt;Start&gt;2006-10-10T21:38:36&lt;/Start&gt;
      &lt;End&gt;2006-10-19T19:38:57&lt;/End&gt;
    &lt;/FieldNotes&gt;
    &lt;FieldNotes run="ORJ09c"&gt;
      &lt;Instrument&gt;
        &lt;Manufacturer&gt;Barry Narod&lt;/Manufacturer&gt;
        &lt;Name&gt;NIMS&lt;/Name&gt;
        &lt;Id&gt;2501-19&lt;/Id&gt;
        &lt;Settings/&gt;
      &lt;/Instrument&gt;
      &lt;Dipole name="Ex"&gt;
        &lt;Length units="meters"&gt;100.000&lt;/Length&gt;
      &lt;/Dipole&gt;
      &lt;Dipole name="Ey"&gt;
        &lt;Length units="meters"&gt;100.000&lt;/Length&gt;
      &lt;/Dipole&gt;
      &lt;Errors&gt;Found data gaps (2). Gaps of unknown length: 1 [945584].&lt;/Errors&gt;
      &lt;SamplingRate units="Hz"&gt;1.000&lt;/SamplingRate&gt;
      &lt;Start&gt;2006-10-19T20:15:46&lt;/Start&gt;
      &lt;End&gt;2006-10-30T18:56:39&lt;/End&gt;
    &lt;/FieldNotes&gt;
  &lt;/RemoteInfo&gt;
  &lt;ProcessedBy&gt;Gary Egbert and Prasanta Patro&lt;/ProcessedBy&gt;
  &lt;ProcessingSoftware&gt;
    &lt;Name&gt;EMTF&lt;/Name&gt;
    &lt;LastMod&gt;1998-03-24&lt;/LastMod&gt;
    &lt;Author&gt;Gary Egbert&lt;/Author&gt;
  &lt;/ProcessingSoftware&gt;
  &lt;ProcessingTag&gt;ORL09bc_J9&lt;/ProcessingTag&gt;
&lt;/ProcessingInfo&gt;
&lt;StatisticalEstimates&gt;
  &lt;Estimate name="VAR" type="real"&gt;
    &lt;Description&gt;Variance&lt;/Description&gt;
    &lt;ExternalUrl&gt;http://www.iris.edu/dms/products/emtf/variance.html&lt;/ExternalUrl&gt;
    &lt;Intention&gt;error estimate&lt;/Intention&gt;
    &lt;Tag&gt;variance&lt;/Tag&gt;
  &lt;/Estimate&gt;
  &lt;Estimate name="COV" type="complex"&gt;
    &lt;Description&gt;Full covariance between each two TF components&lt;/Description&gt;
    &lt;ExternalUrl&gt;http://www.iris.edu/dms/products/emtf/covariance.html&lt;/ExternalUrl&gt;
```

```
    <Intention>error estimate</Intention>
    <Tag>covariance</Tag>
  </Estimate>
  <Estimate name="INVSIGCOV" type="complex">
    <Description>Inverse Coherent Signal Power Matrix (S)</Description>
    <ExternalUrl>http://www.iris.edu/dms/products/emtf/inverse_signal_covariance.html</ExternalU
    <Intention>signal power estimate</Intention>
    <Tag>inverse_signal_covariance</Tag>
  </Estimate>
  <Estimate name="RESIDCOV" type="complex">
    <Description>Residual Covariance (N)</Description>
    <ExternalUrl>http://www.iris.edu/dms/products/emtf/residual_covariance.html</ExternalUrl>
    <Intention>error estimate</Intention>
    <Tag>residual_covariance</Tag>
  </Estimate>
  <Estimate name="COH" type="complex">
    <Description>Coherence</Description>
    <ExternalUrl>http://www.iris.edu/dms/products/emtf/coherence.html</ExternalUrl>
    <Intention>signal coherence</Intention>
    <Tag>coherence</Tag>
  </Estimate>
  <Estimate name="PREDCOH" type="complex">
    <Description>Multiple Coherence</Description>
    <ExternalUrl>http://www.iris.edu/dms/products/emtf/multiple_coherence.html</ExternalUrl>
    <Intention>signal coherence</Intention>
    <Tag>multiple_coherence</Tag>
  </Estimate>
  <Estimate name="SIGAMP" type="complex">
    <Description>Signal Amplitude</Description>
    <ExternalUrl>http://www.iris.edu/dms/products/emtf/signal_amplitude.html</ExternalUrl>
    <Intention>signal power estimate</Intention>
    <Tag>signal_amplitude</Tag>
  </Estimate>
  <Estimate name="SIGNOISE" type="complex">
    <Description>Signal Noise</Description>
    <ExternalUrl>http://www.iris.edu/dms/products/emtf/signal_noise.html</ExternalUrl>
    <Intention>error estimate</Intention>
    <Tag>signal_noise</Tag>
  </Estimate>
</StatisticalEstimates>
```

```
<DataTypes>
  <DataType name="Z" type="complex" output="E" input="H" units="[mV/km]/[nT]">
    <Description>MT impedance</Description>
    <ExternalUrl>http://www.iris.edu/dms/products/emtf/impedance.html</ExternalUrl>
    <Intention>primary data type</Intention>
    <Tag>impedance</Tag>
  </DataType>
  <DataType name="T" type="complex" output="H" input="H" units="[]">
    <Description>Vertical Field Transfer Functions (Tipper)</Description>
    <ExternalUrl>http://www.iris.edu/dms/products/emtf/tipper.html</ExternalUrl>
    <Intention>primary data type</Intention>
    <Tag>tipper</Tag>
  </DataType>
</DataTypes>
<SiteLayout>
<InputChannels ref="site" units="m">
<Magnetic name="Hx" orientation="15.8" x="0.0" y="0.0" z="0.0"/>
<Magnetic name="Hy" orientation="105.8" x="0.0" y="0.0" z="0.0"/>
</InputChannels>
<OutputChannels ref="site" units="m">
<Magnetic name="Hz" orientation="0.0" x="0.0" y="0.0" z="0.0"/>
<Electric name="Ex" orientation="15.8" x="-50.0" y="0.0" z="0.0" x2="50.0" y2="0.0" z2="0.0"/>
<Electric name="Ey" orientation="105.8" x="0.0" y="-50.0" z="0.0" x2="0.0" y2="50.0" z2="0.0"/>
</OutputChannels>
</SiteLayout>
<Data count="2">
  <Period value="7.31429" units="secs">
    <Z type="complex" size="2  2" units="[mV/km]/[nT]">
      <value name="Zxx" output="Ex" input="Hx">-3.092013e0 -2.721066e0</value>
      <value name="Zxy" output="Ex" input="Hy">1.321225e1 9.352477e0</value>
      <value name="Zyx" output="Ey" input="Hx">-4.331750e0 -6.302522e0</value>
      <value name="Zyy" output="Ey" input="Hy">-8.166870e-1 1.109706e0</value>
    </Z>
    <Z.VAR type="real" size="2  2">
      <value name="Zxx" output="Ex" input="Hx">1.128847e-1</value>
      <value name="Zxy" output="Ex" input="Hy">1.580089e-1</value>
      <value name="Zyx" output="Ey" input="Hx">6.515949e-2</value>
      <value name="Zyy" output="Ey" input="Hy">9.120612e-2</value>
    </Z.VAR>
    <Z.INVSIGCOV type="complex" size="2  2">
```

```
    <value output="Hx" input="Hx">3.444128e1 -2.222731e-7</value>
    <value output="Hx" input="Hy">1.809302e0 -2.094002e-1</value>
    <value output="Hy" input="Hx">1.809302e0 2.093998e-1</value>
    <value output="Hy" input="Hy">4.820872e1 4.466731e-7</value>
  </Z.INVSIGCOV>
  <Z.RESIDCOV type="complex" size="2  2">
    <value output="Ex" input="Ex">6.555198e-3 0.000000e0</value>
    <value output="Ex" input="Ey">-3.697359e-4 -1.465000e-4</value>
    <value output="Ey" input="Ex">-3.697359e-4 1.465000e-4</value>
    <value output="Ey" input="Ey">3.783802e-3 0.000000e0</value>
  </Z.RESIDCOV>
  <T type="complex" size="1  2" units="[]">
    <value name="Tx" output="Hz" input="Hx">7.031946e-2 -6.107178e-2</value>
    <value name="Ty" output="Hz" input="Hy">3.806275e-1 1.202571e-2</value>
  </T>
  <T.VAR type="real" size="1  2">
    <value name="Tx" output="Hz" input="Hx">5.365952e-4</value>
    <value name="Ty" output="Hz" input="Hy">7.510919e-4</value>
  </T.VAR>
  <T.INVSIGCOV type="complex" size="1  2">
    <value output="Hx" input="Hx">3.444128e1 -2.222731e-7</value>
    <value output="Hx" input="Hy">1.809302e0 -2.094002e-1</value>
    <value output="Hy" input="Hx">1.809302e0 2.093998e-1</value>
    <value output="Hy" input="Hy">4.820872e1 4.466731e-7</value>
  </T.INVSIGCOV>
  <T.RESIDCOV type="complex" size="1  2">
    <value output="Hz" input="Hz">3.116000e-5 0.000000e0</value>
  </T.RESIDCOV>
</Period>
<Period value="25.60000" units="secs">
  <Z type="complex" size="2  2" units="[mV/km]/[nT]">
    <value name="Zxx" output="Ex" input="Hx">-2.658900e-1 -1.369750e0</value>
    <value name="Zxy" output="Ex" input="Hy">7.020470e0 7.808172e0</value>
    <value name="Zyx" output="Ey" input="Hx">-1.869531e0 -3.936828e0</value>
    <value name="Zyy" output="Ey" input="Hy">-4.361100e-1 -1.222502e-1</value>
  </Z>
  <Z.VAR type="real" size="2  2">
    <value name="Zxx" output="Ex" input="Hx">2.372779e-4</value>
    <value name="Zxy" output="Ex" input="Hy">3.674678e-4</value>
    <value name="Zyx" output="Ey" input="Hx">7.079704e-5</value>
```

```
        <value name="Zyy" output="Ey" input="Hy">1.096420e-4</value>
      </Z.VAR>
      <Z.INVSIGCOV type="complex" size="2  2">
        <value output="Hx" input="Hx">3.539870e-3 -1.293190e-11</value>
        <value output="Hx" input="Hy">-6.276168e-4 1.393000e-4</value>
        <value output="Hy" input="Hx">-6.276168e-4 -1.393000e-4</value>
        <value output="Hy" input="Hy">5.482130e-3 5.657895e-12</value>
      </Z.INVSIGCOV>
      <Z.RESIDCOV type="complex" size="2  2">
        <value output="Ex" input="Ex">1.340602e-1 0.000000e0</value>
        <value output="Ex" input="Ey">-1.257074e-2 4.108000e-3</value>
        <value output="Ey" input="Ex">-1.257074e-2 -4.108000e-3</value>
        <value output="Ey" input="Ey">3.999980e-2 0.000000e0</value>
      </Z.RESIDCOV>
      <T type="complex" size="1  2" units="[]">
        <value name="Tx" output="Hz" input="Hx">-1.483712e-2 -3.318267e-2</value>
        <value name="Ty" output="Hz" input="Hy">2.216339e-1 1.142828e-1</value>
      </T>
      <T.VAR type="real" size="1  2">
        <value name="Tx" output="Hz" input="Hx">2.596495e-6</value>
        <value name="Ty" output="Hz" input="Hy">4.021142e-6</value>
      </T.VAR>
      <T.INVSIGCOV type="complex" size="1  2">
        <value output="Hx" input="Hx">3.539870e-3 -1.293190e-11</value>
        <value output="Hx" input="Hy">-6.276168e-4 1.393000e-4</value>
        <value output="Hy" input="Hx">-6.276168e-4 -1.393000e-4</value>
        <value output="Hy" input="Hy">5.482130e-3 5.657895e-12</value>
      </T.INVSIGCOV>
      <T.RESIDCOV type="complex" size="1  2">
        <value output="Hz" input="Hz">1.467000e-3 0.000000e0</value>
      </T.RESIDCOV>
    </Period>
  </Data>
  <PeriodRange min="7.31429" max="25.60000"/>
</EM_TF>
```

13 CODE LIMITATIONS / TO DO

XML files include links to **HTML definitions** of included data types, as well as all pertinent statistical estimates. These HTML files are yet to be completed and uploaded. In the meantime, please note that these definitions are consistent with the EDI manual.

Derived data types are supported by the XML format. However, correct rotation of derived data types requires recomputation of the primary data types (e.g., impedance, tipper), their rotation, followed by a recomputation of the derived data (e.g., apparent resistivities and phases, tipper magnitude, skew, phase or ellipticity). General implementation of such a capability is a challenging task that is not currently warranted by data archiving needs. Therefore, for now we omit any additional derived data type products on conversion to XML files. If you have a need in any such products, the original EDI files are always included in the archive bundle.

Similarly, any general statistical estimate is supported by the XML format, as long as that estimate relates one or more of primary data type components to each other. However, the inhomogeneity with which, e.g., the **coherence and predicted coherence** information are sporadically recorded in the EDI files, is such that correctly reading and interpreting this information in general is challenging. This work is currently not warranted by the few occurrences of these estimates in the historic EDI files, and the coherences are therefore omitted from the XML files. As with the derived data types, they can always be accessed by downloading the original EDI file.

Finally, during the archiving work we have encountered several occasions of EDI SPECTRA files that have been edited, perhaps manually, to include fewer frequencies than the **NFREQ** value might suggest. Since we want the output XML file to contain a correct frequency count, we have not attempted to overcome this problem programmatically (although we may implement a workaround in the future). In these rare circumstances, conversion to XML will halt and the original EDI needs to be edited to fix the problem (by adjusting NFREQ value to the actual number of frequencies in file).

14 CONCLUDING REMARKS

The MT format conversion utilities EMTF FCU, and the corresponding EMTF XML data format, have the following basic intentions:

1. Provide a more modern and general alternative to the EDI standard that would accommodate a wider range of EM TFs; and

2. Allow for easy archiving and sharing of historic and modern EM TFs in a searchable, widely available online database.

Hope that my tools facilitate these objectives. These tools have been tested (and worked!) on over 5000 historical data files stored in a wide variety of EDI flavors, as well as Z-files, from at least 55 surveys, worldwide. At this point, I believe that the conversion tools are appropriately robust. Having said that, there is still room for improvement. These tools are open source and easy to edit; please contribute your efforts back to us. Comments also welcome.

Enjoy!

References

Becken, M., O. Ritter, and H. Burkhardt (2008), Mode separation of magnetotelluric responses in three-dimensional environments, *Geophysical Journal International*, *172*(1), 67–86, doi: 10.1111/j.1365-246X.2007.03612.x.

Eisel, M., and G. D. Egbert (2001), On the stability of magnetotelluric transfer function estimates and the reliability of their variances, *Geophysical Journal International*, *144*, 65–82.

Hobbs, B. A. (1992), Terminology and symbols for use in studies of electromagnetic induction in the Earth, *Surveys in Geophysics*, *13*(4-5), 489–515, doi:10.1007/BF01903487.

Wight, D. E. (1988), SEG Standard For MT And EMAP Data, in *1988 SEG Annual Meeting, October 30 - November 3, 1988 , Anaheim, California*, pp. 1–3.